Identification of new physics and general WIMP search at the ILC

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We investigate the possibility of the identification of TeV physics models including WIMP dark matter at the International Linear Collider. Many TeV physics models contain a WIMP dark matter (χ^0) and charged new particle ($\chi^\pm$) which interacts with the WIMP dark matter via the vertex $\chi^\pm \chi^0 W^\mp$. Through Monte Carlo simulations, we study the process, $e^+ e^- \to \chi^+ \chi^- \to \chi^0 \chi^0 W^+ W^-$, because the signal contains the fruitful information of the model. We show that, in particular, the distribution of the $\chi^\pm$ production angle is the powerful probe in the TeV physics model search.

1 Introduction

About 23 % energy density of the present Universe is made up of dark matter and it plays a key role in the large structure formation. However, we don't know what it is. Dark matter candidates don't exist in the standard model (SM).

Weakly Interacting Massive Particle (WIMP) is one of the most plausible candidate for dark matter. It is neutral, massive, and sufficiently stable particle and such particle naturally explains the observed dark matter abundance, $\Omega_{DM} h^2 \sim 0.11$ [1]. Many models of physics beyond the SM including WIMP dark matter have been proposed.

The TeV physics could be produced at the Large Hadron Collider (LHC) and the International Linear Collider (ILC). The LHC is now operating, but the precision measurement of events including dark matter in final state is difficult at the experiments. On the other hand, it would be possible at the ILC. The measurements is important for not only dark matter physics but also identification of the TeV new physics model.

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Models	Particles	Spins
Inert Higgs like model	$(\chi_S^\pm, \chi_S^0)$	(0, 0)
SUSY like model	$(\chi_F^\pm, \chi_F^0)$	(1/2, 1/2)
Little Higgs like model	$(\chi_V^\pm, \chi_V^0)$	(1, 1)
(1, 0) model	$(\chi_V^\pm, \chi_S^0)$	(1, 0)
(0, 1) model	$(\chi_S^\pm, \chi_V^0)$	(0, 1)

Table 1: Classification of spin configuration of new particles.

In this study, we investigate the possibility of general WIMP search and new physics model identification studying $e^+e^- \to \chi^+\chi^- \to \chi^0\chi^0 W^+W^-$ process at the ILC, where χ^0 and $\chi^\pm$ denote the WIMP and the charged new particle, respectively. Using the process, we have already studied about the possibility of precision measurements of the Little Higgs model [2]. We have shown that we can extract fruitful information from the signal of the process: The masses of $\chi^\pm$ and χ^0 can be determined from the edges of the energy distribution of the reconstructed W bosons. It is also possible to confirm that the spin of $\chi^\pm$ and the vertex structure using the angular distribution of the $\chi^\pm$ pair procudion and the polarization of $W^\pm$. The gauge charges of the $\chi^\pm$ boson could be measured using a polarized electron beam.

It is worth noting that such process exists in many TeV physics models which explain the smallness of electroweak scale , because WIMP candidates would interact with the SM particles weakly. Thus, the process plays a key role of the general WIMP search.

2   Benchmark models and representative points

We concentrate on the WIMP dark matter(χ^0) and the charged new particle ($\chi^\pm$) which interacts with dark matter. The interaction vertex, $\chi^\pm\chi^0 W^\mp$, is also exist in many TeV physics models which contain WIMP scenario. All spin combinations which has the vertex is written in Table 1, keeping charge, gauge, discrete symmetry and Lorentz invariance.

In this study, we investigate the Inert Higgs doublet like model (IH) [3], supersymmetric like model (SUSY) [4], and Littlest Higgs like model (LHT) [5]-[11] as benchmark models of $\chi^\pm$ spin 0, 1/2, and 1, respectively . The crucial difference from the (1,0) and (0,1) models in Table 1 only appears in the what relates with the $\chi^\pm\chi^0 W^\mp$ vertex (e.g. the shape of the energy distribution of W bosons).

At representative points, we take the same new particle masses and production cross section in each models in order to investigate the separation possibility of the TeV new physics model using the same masses and number of events. Actually, when we discuss the features of new particles which observed at future colliders, we compare the signal with the sample models in the same way. The parameters at the representative points are summarized in Table 2.

Since the mass difference of new particles is determined in littlest Higgs model explicitly, the mass differences at representative points are adjusted to coincidence with Littlest Higgs model. We take the coefficients of vertices to consistent with a parameter in each models which realizes the mass difference. However, in order to adjust the amplitude of cross section to each other, the over all of neutral couplings (e.g. $\chi^+\chi^- Z$) are normalized.

	$m_{\chi^\pm}$ [GeV]	m_{χ^0} [GeV]	Cross section	Br($\chi^\pm \to \chi^0 W^\pm$)
$\sqrt{s} = 500$ GeV	231.57	44.03	40, 200 [fb^{-1}]	$\sim 100\%$
$\sqrt{s} = 1$ TeV	368	81.9	40, 200 [fb^{-1}]	$\sim 100\%$

Table 2: Representative points in this study

Detector	Performance	Coverage
Vertex detector	$\delta_b \leq 5 \oplus 10/p\beta \sin^{3/2}\theta$ (μm)	$|\cos\theta| \leq 0.93$
Central drift chamber	$\delta p_t/p_t^2 \leq 5 \times 10^{-5}$ (GeV/c)$^{-1}$	$|\cos\theta| \leq 0.98$
EM calorimeter	$\sigma_E/E = 17\%/\sqrt{E} \oplus 1\%$	$|\cos\theta| \leq 0.99$
Hadron calorimeter	$\sigma_E/E = 45\%/\sqrt{E} \oplus 2\%$	$|\cos\theta| \leq 0.99$

Table 3: Detector parameters used in our simulation study.

In this paper, we show the study at $\sqrt{s} = 1$TeV with an integrated luminosity of 500 fb^{-1}. The study at $\sqrt{s} = 500$GeV is written in [12].

3 Simulation tools

In our study, both signal and background events have been generated by Physsim [13]. The initial-state radiation and beamstrahlung have been included in the event generations. We have ignored the finite crossing angle between the electron and positron beams. In the event generations, helicity amplitudes were calculated using the HELAS library [14], which allows us to deal with the effect of gauge boson polarizations properly. Phase space integration and the generation of parton 4-momenta have been performed by BASES/SPRING [15]. Parton showering and hadronization have been carried out by using PYTHIA6.4 [16], where final-state tau leptons are decayed by TAUOLA [17] in order to handle their polarizations correctly.

The generated Monte Carlo events have been passed to a detector simulator called JS-FQuickSimulator, which implements the GLD geometry and other detector-performance related parameters [18]. In the detector simulator, hits by charged particles at the vertex detector and track parameters at the central tracker are smeared according to their position resolutions, taking into account correlations due to off-diagonal elements in the error matrix. Since calorimeter signals are simulated in individual segments, a realistic simulation of cluster overlapping is possible. Track-cluster matching is performed for the hit clusters in the calorimeter in order to achieve the best energy flow measurements. The resultant detector performance in our simulation study is summarized in Table 3.

4 Signal Selection

We use events in which both W bosons decay hadronically, $e^+e^- \to \chi^+\chi^- \to \chi^0\chi^0 W^+W^- \to \chi^0\chi^0 qqqq$, as signal events. Thus, the main background processes are W^+W^-, $\nu\bar{\nu}W^+W^-$, etc.

	Physics model	$\sigma = 40$ fb	$\sigma = 200$ fb
$M_{\chi^\pm}$ (GeV)	IH	364.3 ± 6.0	366.4 ± 1.4
	SUSY	370.6 ± 5.6	368.0 ± 1.3
	LHT	367.7 ± 4.0	367.4 ± 0.9
M_{χ^0} (GeV)	IH	79.7 ± 4.8	78.5 ± 1.2
	SUSY	76.6 ± 6.5	77.8 ± 1.3
	LHT	78.0 ± 3.9	78.7 ± 0.9

Table 4: Measurement accuracy of masses of $\chi^\pm$ and χ^0.

In order to identify the two W bosons from $\chi^\pm$ decays, two jet-pairs have been selected so as to minimize a χ^2 function,

$$\chi^2 = (^{\mathrm{rec}}\mathrm{M}_{W1} - \,^{\mathrm{tr}}\mathrm{M}_W)^2/\sigma^2_{\mathrm{M}_W} + (^{\mathrm{rec}}\mathrm{M}_{W2} - \,^{\mathrm{tr}}\mathrm{M}_W)^2/\sigma^2_{\mathrm{M}_W}, \tag{1}$$

where $^{\mathrm{rec}}\mathrm{M}_{W1(2)}$ is the invariant mass of the first (second) 2-jet system paired as a W candidate, $^{\mathrm{tr}}\mathrm{M}_W$ is the true W mass (80.4 GeV), and σ_{M_W} is the resolution for the W mass (4 GeV). We required $\chi^2 < 26$ to obtain well-reconstructed events.

Since χ^0 escape from detection resulting in a missing momentum, we have thus selected events with the missing transverse momentum $^{\mathrm{miss}}p_{\mathrm{T}}$ above 84 GeV. We have also selected events with a energy of W below 500 GeV. The number of remaining background events is much smaller than that of the signal after imposing all the cuts.

5 Mass Determination

The Masses of new particles, χ^0 and $\chi^\pm$, can be determined from the edges of the W energy distribution. After subtracting the backgrounds, the distribution has been fitted with a line shape determined by a high statistics signal sample. The fitted masses of χ^0 and $\chi^\pm$ are summarized in Table 4. The masses of $\chi^\pm$ and χ^0 will be determined with $\mathcal{O}(1)\%$ accuracy.

6 Angular Distribution

The production angle of $\chi^\pm$ can be calculated with 2-fold ambiguity from the momenta of W bosons, assuming back-to-back production of χ^+ and χ^-. Figure 1 shows 2-dimensional histogram. To estimate the possibility of the new physics model identification, we compare the distribution with the "template" which is the distribution of high statistics signal samples using χ^2 analysis:

$$\chi^2 \;\; = \;\; \frac{N_{\mathrm{Data}} - N_{\mathrm{Temp}}}{\sigma_{\mathrm{Sig+BG}}}, \tag{2}$$

where N_{Data} and N_{Temp} are the number of the data and the number of the template at each bin, respectively. The $\sigma_{\mathrm{Sig+BG}}$ is the error of the signal and backgrounds. The χ^2 values are summarized in Table 5. It shows that the identification of these new physics models is possible by comparing of production angles of $\chi^\pm$.
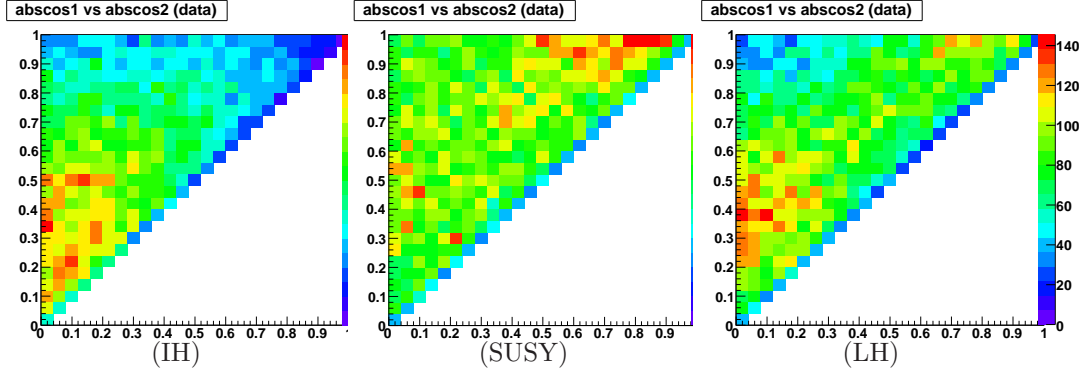
Figure 1: The 2-dimensional histogram for the two solutions of the two solutions of the $\chi^\pm$ production angle at each models.

σ	Model	IH template	SUSY template	LHT template
40 fb	IH	1.2	4.7	3.6
	SUSY	5.2	1.2	3.2
	LHT	3.7	2.6	1.2
200 fb	IH	1.0	17.3	11.0
	SUSY	20.0	1.0	9.2
	LHT	13.7	7.8	1.0

Table 5: Summary of $\chi^2/$(the number of bins) values from 2-dimensional histograms of the $\chi^\pm$ production angle.

7 Summary

We study the possibility of general WIMP search and new physics model identification using $e^+e^- \to \chi^+\chi^- \to \chi^0\chi^0 W^+W^-$ process at the $\sqrt{s} = 1$ TeV ILC with integrated luminosity of 500 fb^{-1}. We have shown that the masses of new particles can be determined very accurately at the ILC in a model independent way. Furthermore, using χ^2 analysis, the identification of new physics models is possible by comparing of the $\chi^\pm$ production angles. Finally, we have also studied the threshold scan to separate the new physics model. It shows that the SUSY like case will be separate from other models.

Acknowledgments

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